1377

The Chemistry of Cigar Smoke
I. An Automatic Smoking Machine for Cigars

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Introduction

In connection with a study of the chemical composition and properties of cigar smoke, it became necessary to design and construct an apparatus having the following features:

1. Smoke cigars automatically.
2. Have a large enough capacity to permit the accumulation of smoke from a number of cigars.
3. Approximate the smoking characteristics of the human in order to provide smoke of the type consumed by the average cigar smoker.

After an examination of the literature and observation of the devices used for smoking cigarettes and cigars in various laboratories, it was decided to construct a machine of the constant-volume type. It was believed that such a machine would provide the greatest versatility and be the simplest to construct.

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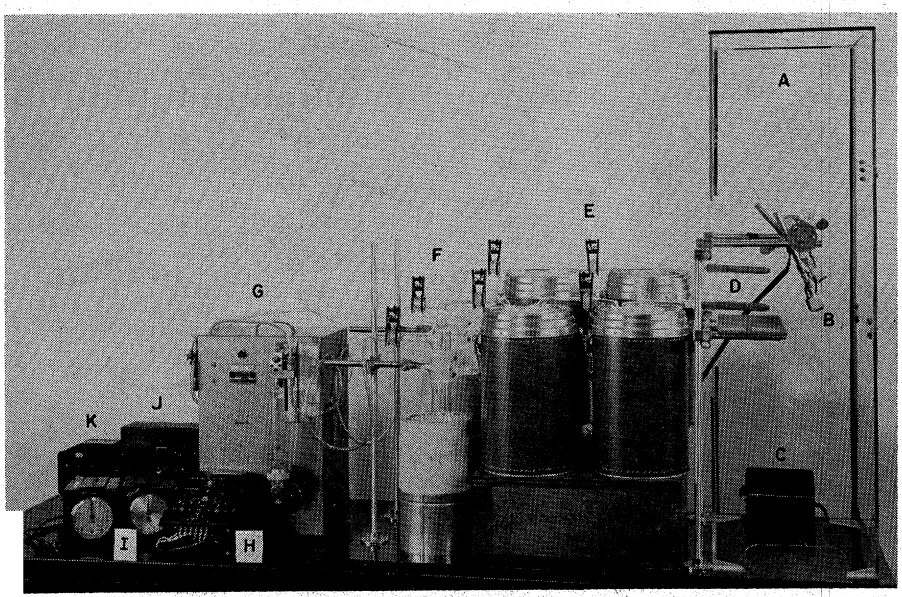

Figure 1. Cigar smoking machine, general view. Legend: A = Plastic chimney; B = Cigar lighters; C = Transformer for lighters; D = Cigars and cigar holders; E = Coiled traps in Dewar flasks; F = Straight-tube safety traps; G = Filamatic pump; H = Repeat Cycle Timer; I = Electric clocks; J = Junction box; K = Constant voltage transformer.

Materials and Construction

The complete smoking machine is shown in **Figure 1.** It consists of two parallel smoking trains enabling two cigars to be smoked simultaneously. The smoke is collected by condensation in glass coils at low temperature. The essential parts of this machine are given in the legend accompanying **Figure 1.**

The plastic chimney surrounds the cigars and prevents disturbance from extraneous side drafts without restricting the normal circulation of air. It is constructed of ¼ inch Plexiglas,[3] 40 x 17 x 12 inches in size, and is open at the top and bottom. There is an open panel at the back to allow the cigars, holders and lighters to extend into the chimney and a drop panel in the front for accessibility.

The lighters are the ordinary six-volt automobile type with lead wires soldered on and wrapped in asbestos cord. They are mounted in laboratory clamps and suspended from above in such a fashion that they are free to pivot on a counter-balance principle. This makes it a simple matter to hold the lighters against the cigars to light them; then releasing the lighters allows them to swing back out of the way. A six-volt, 108 watt transformer connected to the lighters in parallel provides

[3] *Mention of a specific commercial product does not constitute an endorsement by the United States Department of Agriculture over other similar items not mentioned.*

the energy necessary for their operation.

The cigars are held in specially built glass holders having S. T. 14/20 male joints and an overall length of approximately 2½ inches. To insure a good fit of the cigar in the holder and provide ample support without pinching or leakage, a steel model of the particular type of cigar to be smoked is first made and is then used by the glass blower as a mold in shaping the holders. In only rare instances has it been necessary to use a coating of ethyl cellulose to prevent side leakage between the cigar and holder.

The smoke is collected by condensation at —70° C in two glass coiled traps, in series, suspended in a mixture of dry ice and acetone. A detailed view of the trap design is given in **Figure 2.** This coiled structure affords several advantages:

1. Large surface area for efficient condensation; the coil consists of almost four feet of 12 mm O.D. tubing.
2. The one-piece design requires a minimum of connections; it provides ease in handling and rinsing.
3. The dimensions chosen allow the trap to fit into a one-gallon Dewar flask (The American Thermos Products Company, Norwich, Conn., No. 820) and be suspended by its own arms without use of any clamps. This permits a very simple installation of the glass portion of the apparatus.

Following the coiled traps in each condensation train is a conventional straight-tube, two-piece, vacuum trap[4] suspended in a half-gallon Dewar flask of dry ice and acetone. The efficiency of the coiled traps is evident from the fact that only a very small amount of condensate is found in the safety trap. A small adapter is used to make connection with the tubing leading to the pump.

The entire glass apparatus is shown in **Figure 3.** Semi-ball joints are utilized wherever possible; these are all S. B. 28/15. The coiled traps are made with either two semi-ball joints or with one semi-ball and one S. T. 14/20 joint, depending on whether it is to be used as a first trap, with connections to the cigar holder, or as a second trap in the series. The safety trap contains an S. T. 45/50 joint. White petrolatum, U.S.P., is used as a grease on all glass joints.

A Filamatic Vial Filler (National Instrument Company, Baltimore, Maryland) was selected as the vacuum source or pump, since it provides flexible programming and is adaptable to multiple smoking modifications (O'Keeffe and Lieser, 1958). The particular model chosen is a Filamatic Duplex, Model DAB, having two pistons, permitting two cigars to be smoked simultaneously yet independently. (Only one piston is visible in **Figure 1**). It was purchased with the following accessories:

1. Single shot attachment.
2. Automatic counter.
3. Two 50 ml syringes.
4. Sapphire ball valves in lieu of the standard steel valves. All other parts are standard equipment on the instrument.

When the Filamatic Vial Filler was received from the manufacturer it was discovered that certain adjustments and modifications were needed. First, it was adjusted so that both pistons would be in phase and would start and stop at the maximum point in the stroke cycle. For this it was necessary to reset the cam shaft and realign the positions of the two pistons on it. Then the micro switch on the cam shaft had to be repositioned so as to stop the pump just as pistons reached the top of the stroke. Secondly, the speed control potentiometer was found to be too course, making it extremely difficult to set and reproduce settings to accurately control the speed of the pumping cycle. This was remedied by the addition of a secondary potentiometer (10,000 ohms) in series with the main control. Next, the automatic counter buzzer noise became very objectionable. Since it was caused by the pulsating current vibration of the armature, it was impossible to eliminate it without changing to direct current operation. Accordingly, the counter energizing lines were transferred to two C-batteries, providing the necessary 30 volts for operation. These are mounted on a shelf inside the Filamatic housing and are accessible from the rear panel.

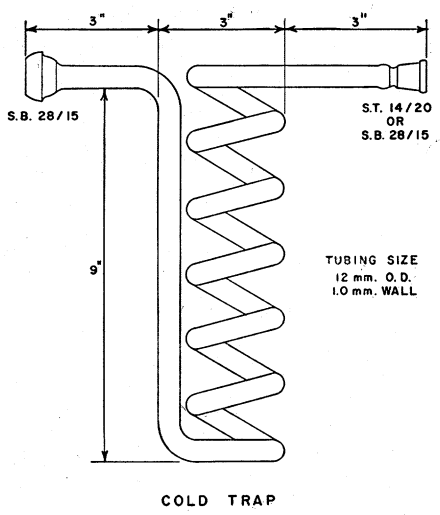

Figure 2. Cold trap.

To interrupt the pumping cycle of the Filamatic machine and furnish the desired puff rate, a Repeat Cycle Timer (G. C. Wilson and Company, Huntington, West Virginia, Model No. 1) is used. This is an electronic instrument in which both the "on" and "off" cycles are adjustable. It was found, however, that the two potentiometers by which these cycles are controlled were much too coarse, making it very difficult to set the desired intervals. To remedy the situation both the "on" and "off" circuits were modified. The "off" circuit was easily corrected by a 50 Megohm resistor added to the resistance across the Hi-Lo range switch. The modification necessary for the "on" cycle circuit was more extensive. A fine control circuit was superimposed on the original control potentiometer. It consisted of two fixed resistances

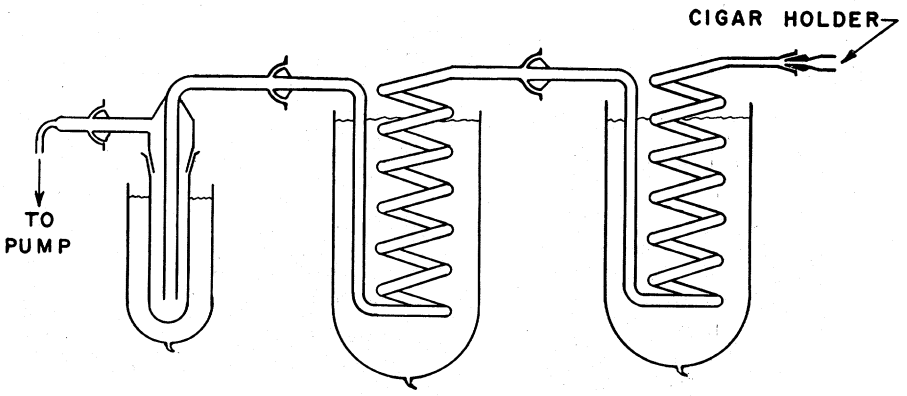

Figure 3. Complete condensation train.

[4] *Scientific Glass Apparatus Company, Bloomfield, N. J., J-4339, Diameter 41 mm.*

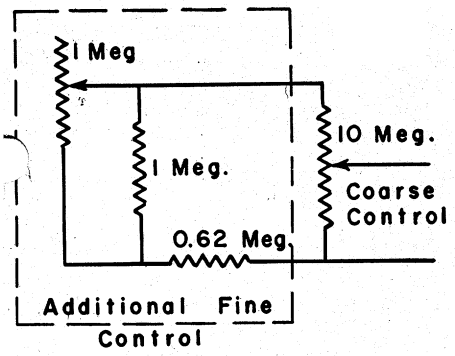

Figure 4. Diagram of "on" cycle modification.

and another potentiometer, as shown in **Figure 4.** By means of the combination of both the original coarse potentiometer and the additional fine potentiometer it is possible to set and control the "on" cycle with ease and accuracy.

Calibration of the puff-time or "on" cycle and of the relaxation-time or "off" cycle is accomplished by two electric clocks (Standard Electric Time Company, Springfield, Massachusetts) which are connected to the Repeat Cycle Timer and record both cycles for each puff as the cigars are smoked. They may be described as follows:

1. For the "on" cycle: Model S-10 Precision Timer, electric, with reset device, on-off extension switch, scale calibration in tenths of a second with accumulation to 1000 seconds, 10 seconds per revolution, 115 volt, 60 cycle.

2. For the "off" cycle: Model S-100 Precision Timer, same as above except 100 seconds per revolution, accumulation to 6000 seconds, calibrated in fifths of a second.

A "plug-in" junction box is used to house the labyrinth of electrical lines necessary for all of the connections between the electrical components of the apparatus and the power source. **Figure 5** gives the wiring details of the junction box and shows its relationship with the various components in block form.

In order to level off the variations in voltage of the laboratory lines, to which the Repeat Cycle Timer is sensitive, a constant voltage transformer is incorporated into the power line of the timer. The particular one used is a Sola, No. 3000: primary voltage 95-125, volt-amps 30, frequency 60, phase 1; secondary voltage 115, 0.26 amps.

Calibration and Operation

It is extremely difficult to determine the smoking habits of the "average" human smoker. Attempts have been made by having people smoke into various machines and using kymographic equipment or even by simple observation. These methods have not proven entirely successful since, under such conditions, subjects do not smoke according to their normal patterns. Also, one finds large differences in natural habits from one individual to another. These problems and the variety of smoking devices that have been developed in attempting to overcome them, in the case of cigarettes, have been discussed by Schur and Rickards (1957) and by Keith and Newsome (1957).

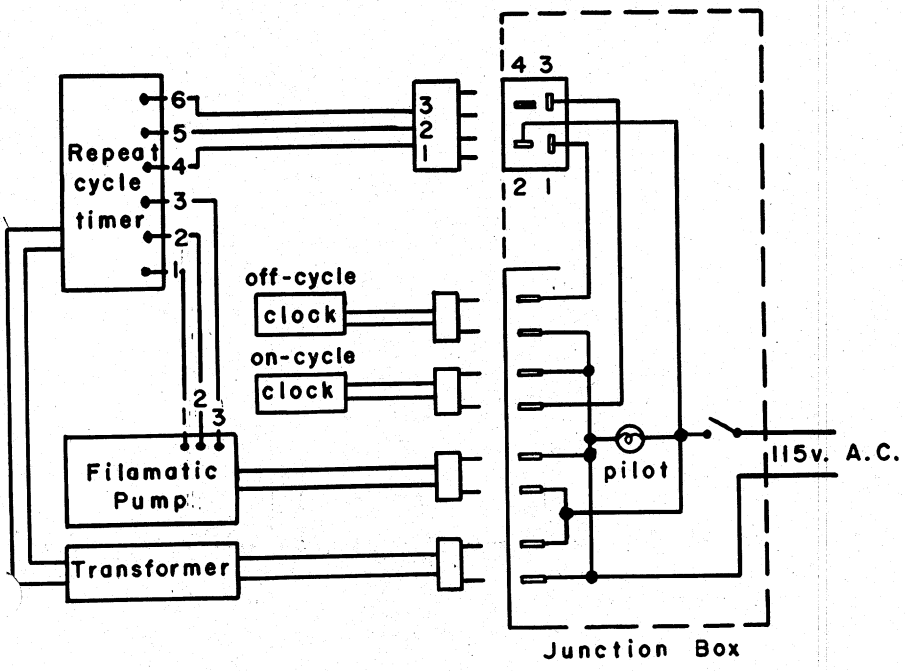

Figure 5. Schematic diagram of electrical equipment.

The smoking habits of the cigar smoker are probably different from those of the cigarette smoker. In the absence of any concrete evidence in this regard, however, the above cigar smoking machine is operated under the same conditions as are generally used for cigarette smoking machines. These are:

Rate—1 puff/minute
Duration of puff—2 seconds
Volume of puff—35 ml.

This does not mean that the apparatus is at all limited to these conditions. Should others be desired, it is a relatively simple task to obtain any settings within the following limits:

Puff volume 0.05 to 50 ml
Puff duration—0.15 to 100 seconds
Puff frequency—0.05 to 275 seconds.

The steps involved in the calibration of the Repeat Cycle Timer and Filamatic units by which the correct settings for the chosen conditions (2 second puff, once a minute, of 35 ml volume) are obtained may be outlined as follows:

1. Calibration of the timer is done by means of the two clocks. By empirical testing, the proper settings for both cycles are found which will give an "on" cycle of four seconds and an "off" cycle of 56 seconds. (This is done so that the pump can be set for a four-second cycle, the down stroke of the pistons taking two seconds and thus providing a two-second puff.) Adjustments are made until the reproducibility of the intervals is at least 99 per cent.

2. The micro switch on the cam shaft of the pump is released by opening up the side door. This places all control of the pump on the timer. The pump is turned on and the settings of both the coarse and fine speed controls are adjusted until the pistons make exactly one cycle in the four seconds allowed by the timer, returning to the top-of-stroke position as determined by vertical alignment.

3. The side door is now replaced, allowing the micro switch again to control the shut-off of the pump cycle.

4. To have the micro switch control the shut-off of the pump, the "on" cycle of the timer cannot be allowed to run at four seconds, since this causes competition of the electronic system with the mechanical shut-off of the micro switch. Also, we must still set the "off" cycle at 58 seconds for a puff per minute rate. The timer controls are therefore readjusted for an "on" cycle of two seconds and an "off" of 58 seconds, to a reproducibility of 99 per cent or better. These are the final

settings and are the ones used in the actual operation of the machine. The combination of the Repeat Cycle Timer to initiate the pumping cycle and the mechanical operation of the micro switch to shut it off has proven to be the major factor in reproducing the correct "on" and "off" cycles. If the timer were allowed to control both parts of the pumping cycle, the accumulation of error in the electronic system would cause the pistons to stop at varying positions. The mechanical cut-off of the micro switch eliminates this difficulty.

5. The proper settings of the pistons are next determined in order to deliver the desired 35 ml volume. This is done by adjusting the micrometer setting for each piston until the correct volume of water is pumped through the piston. The micrometer is set approximately by use of cylinders to measure the water delivered; the final adjustment to 35.0 $\pm$ 0.1 ml is made by weighing the water in small beakers. Since the necessary micrometer setting for each syringe and assembly is different, the syringe number, a valve head identification letter and the micrometer value are marked on the instrument near each piston mounting.

In actual operation, the cigars are lighted on the first puff and are allowed to smoke down to a preset distance of ⅔ of their length. This may require anywhere from 50 to 70 puffs, depending on the particular brand being smoked. After ⅔ of the cigar is smoked, it is replaced by a fresh one and the process continued, the smoke being allowed to condense and accumulate in the cold traps. The condensate from 50 to 55 cigars may be collected continuously over a period of five days, providing a small amount of dry ice is added to the Dewar flasks each day. After the condensate is collected, the apparatus is dismantled, all grease is removed from the joints, and the traps are rinsed out with appropriate solvents. The condensed smoke is now available for further study.

During the smoking of each group of cigars, daily checks are made on the timing cycles to assure a maximum average error of less than one per cent. Thus we are certain of a reproducibility of 99 per cent in the mechanical operation of the smoking machine. This machine has been designed for the collection of smoke from a large number of cigars rather than for the quantitative analysis of smoke from individual cigars.

Summary

The design and construction of an automatic smoking machine for cigars is described in detail. This device is of the constant-volume type and is provided with specially designed cold traps so that the smoke from a large number of cigars may be collected and accumulated by low temperature condensation. Two cigars are smoked simultaneously. The pumping and electronic timing systems may be purchased from commercial sources, but require certain modifications for necessary accuracy. The reproducibility of the machine's mechanical operation is 99 per cent or better.

Acknowledgments

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